Advanced Vehicles and Energy Storage

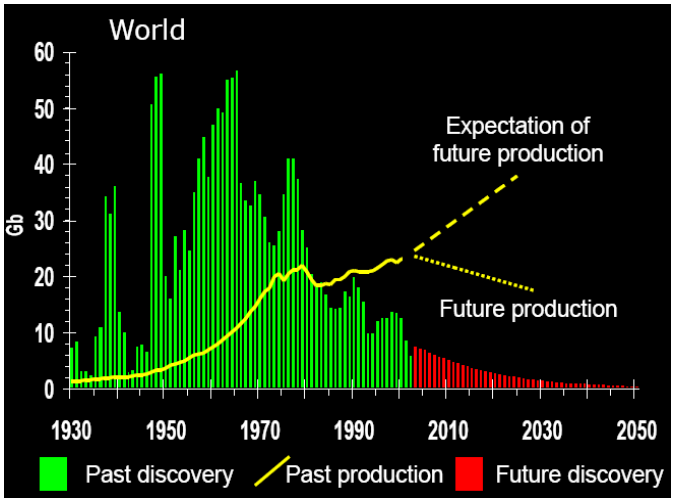
Tim Murphy, Manager
Energy Storage and Transportation Systems

Michael C. Hagood
Energy Systems Business Line Lead

Utah Energy Forum March 24, 2008

Energy Security

- The United States faces an unprecedented threat to its economic and national security due to its dependence on foreign oil and gas, in particular transportation fuel derived from geopolitically unstable or “unfriendly” countries.
- This is a chronic disease that diminishes our country’s strength, and, given demand trends, will only worsen.
- However, an even more serious consequence may soon result from potential “acute” disruptions in a vulnerable energy-supply chain.



World Conventional Oil (in Billions of Barrels)

“I question whether the supply (of oil) will be developed to meet demand expectations. I believe demand is going to be constrained by supply”

Chair and Chief Executive
ConocoPhillips, James J. Mulva

DOE - Energy Efficiency & Renewable Energy

We support U.S. Department of Energy's effort to reduce national dependence on foreign oil through:

- DOE/EERE Vehicle Technologies Program
  - Technology and Infrastructure Development
  - Field testing and demonstrations of advanced vehicles and systems
  - Advanced battery development and testing
  - Advanced Energy Initiative
    - "better batteries for hybrid and electric cars"
      - » Excerpt from President Bush's State of the Union Address, Jan. 2006

Advanced Vehicle Technology

- Vehicle Technologies Program
  - DOE Advanced Vehicle Testing Activity (AVTA)
    - Hydrogen ICE
    - EV and HEV
    - Plug-in HEV (PHEV)
    - Power Electronics
    - PHEV grid interaction studies
    - Fueling Infrastructure
    - Fuel type testing (Ethanol and Bio-diesel fuels Planned)
    - Vehicle energy storage (Batteries and Capacitors)
    - Heavy vehicle technology

AVTA Focus

Provide benchmark data for DOE technology modeling, simulations, research and development activities, as well as to fleet managers and other vehicle purchasers for informed purchase and operations decisions.

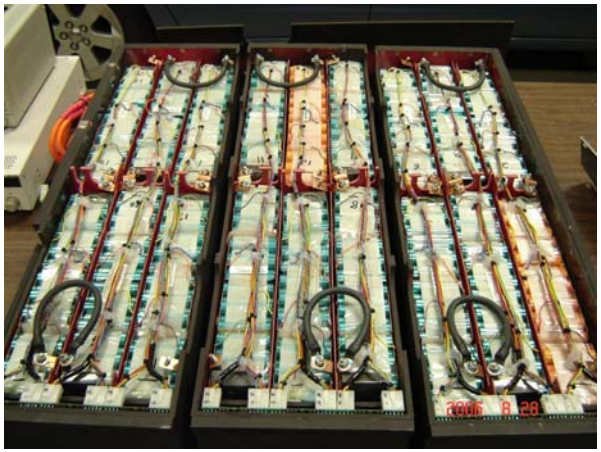
- Develop partnerships with public, private, and regional groups to test, deploy and demonstrate advanced vehicle technology.

AVTA Testing Partners - Sample

- Vehicle Testing Partners (cost sharing)
  - Electric Transportation Applications (lead)
  - Arizona Public Service
  - Bank One
  - Red Cross
  - Ford Motor Company
  - Luke AFB
  - New York Power Authority
  - Southern California Edison
  - Salt River Project
  - City of Phoenix
  - New York State (NYSERDA)
  - Washington State (Seattle, Ports, King County, Others)
  - Various California cities, universities
  - State of Hawaii
  - National Rural Electric Cooperative

AVTA Testing History

- Hybrid electric vehicles
  - 13 models, 3.5 million test miles
- Hydrogen ICE (internal combustion engine) vehicles
  - 6 models, 400,000 test miles
- Full-size electric vehicles
  - 40 EV models, 5+ million test miles
- Neighborhood electric vehicles
  - 15 models, 200,000 test miles
- Urban electric vehicles
  - 3 models, 1 million test miles
- Plug-In Hybrid Electric Vehicles
  - Just getting started (Hundreds of Miles)



Vehicle Testing Methods

- Baseline performance testing
  - Coastdown, acceleration, maximum speed, braking, handling & two fuel-use drive cycle tests (SAE J1634) one A/C on & one A/C off
  - Highly repeatable & controlled, allows vehicle-to-vehicle comparisons
  - Conduct battery capacity & power testing
- Fleet testing
  - Fuel use and type, miles, maintenance, repairs, insurance, registration, life cycle costs
  - With & w/o onboard data loggers
  - For HEVs, two of each model accumulate 160,000 fleet miles in 36 months
- Accelerated testing
  - Utilizes dedicated drivers
  - Specific drive protocols
  - With & w/o onboard data loggers
  - Fuel use and type, miles, maintenance & repairs
- End-of-life testing
  - Conduct battery capacity & power testing
  - Fuel use drive cycle tests A/C on & A/C off

APS Hydrogen Pilot Plant

- Partners include Arizona Public Service (APS)
- First & longest operating hydrogen station in the U.S., since June 2002
- 9,000 kg of hydrogen produced onsite - 99.9997% purity
- 11,000+ hydrogen, HCGN & CNG fueling events


City of Phoenix
Fire Department

FIRE PERMIT

150 South 12th Street
Phoenix, Arizona 85034
General Information (602)262-7462

POST THIS PERMIT ON JOB SITE

Permit # F203 0200731 Issue Date 05-MAR-2002 Expires 02-MAR-2012
Permit Description FUEL DISPENSING @ 435 S. 2ND AVE.
Project 99-22738 APS
Address NOT FOUND Zoning
Description/Scope of Work: MOTOR VEHICLE FUEL DISPENSING STATION
MOTOR VEHICLE FUEL-DISPENSING STATIONS:
Operate.
PERMITEE:
APS/Pinnacle West

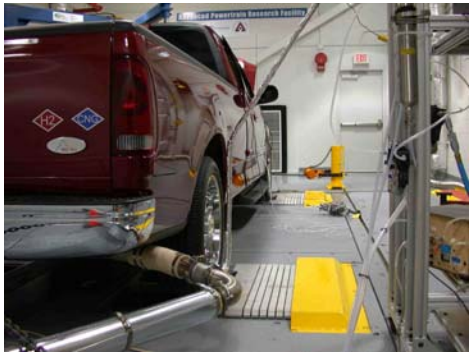
THIS PERMIT IS NOT TRANSFERRABLE

COPY RECEIVED BY DATE 3/29/07
FIRE CAPTAIN DATE 3/29/07

CUSTOMER COPY

Hydrogen ICE Vehicle Testing

- 15%, 30% & 50% HCNG-fueled ICE vehicles
- 100% hydrogen ICE vehicles
- 500,000 hydrogen & HCNG miles by Dec 2007



HEV Testing

Commercial and experimental vehicles

Plug-in hybrid vehicles (PHEV)

- Developed PHEV test plan, includes:
  - Baseline performance testing
  - Accelerated testing
  - Fleet testing
- Developed PHEV test procedures
- Validated test procedures using conversion PHEVs
  - EnergyCS Prius
  - Renault Kangoo
  - Hymotion conversion vehicles
- Eventually test production PHEVs
  - DOE demonstration solicitation 2008
    - OEM Partnerships
    - INL, data collection

PHEV Charging and Economic Analysis

- Understand the requirements & costs of PHEV charge infrastructure, along with the additional costs for onboard power electronics & added battery requirements for PHEVs
- PHEV trip analysis – vehicle survey & actual PHEV use
- Infrastructure cost analysis based on:
  - Overnight home garage charging
  - Overnight apartment complex charging
  - Opportunity charging at a commercial facility
- PHEV vehicle component cost analysis based on:
  - Charge infrastructure
  - Electrical energy for charging
  - Additional onboard power electronics required for PHEV charging
  - Probable vehicle changes to accommodate various charging options
  - Additional battery capacity to support charge depleting (deep cycle) operation
- PHEV cost effectiveness versus “standard” HEV

Additional PHEV Grid Activities

Engage public utilities, collect data

- Site Evaluations and economic/infrastructure impacts
  - Deploy vehicles at various sites and conduct charging pattern evaluations for real world data on loads and charging use patterns as well as other V2G connection challenges.
  - Work with utilities to determine grid distribution and infrastructure issues associated with PHEV load growth.
  - Catalog regulatory requirements impacting PHEV connections to the grid.
  - Economic and generation issues and impacts in partnership with utilities.
  - Vehicle and Battery to Grid testing profiles
    - Level I, II, and III bidirectional current flows, issues

Vehicle Energy Storage

Electrochemical systems

- Advanced Electrochemical Energy Storage
  - Procedures, testing, and analysis
  - Product benchmarking
  - Applied research, development and computer modeling
- Most of the departmental R&D involves electrochemical applications
  - Lithium ion batteries
  - Advanced Lead Acid (micro or light hybrids)
  - Electrochemical capacitors

INL Approach

①

Testing

USABC and Other program deliverables

- Batteries
- Ultracapacitors

Cells, Modules, and Full Size Systems

Testing protocol is driven by customer needs (FreedomCAR, USABC, and others).

②

Analysis

Standards developed for data acquisition, analysis, quality, and management.

Data accuracy and uncertainty analysis.

Huge amounts of data are generated.

Software analysis tools have been developed (HPPCalc).

③

Modeling

Key tools are under development:

- Arrhenius Behavior
- Equivalent Circuit Models
- Life Prediction Models
- TLVT protocol
- Sigmoid Models

④

R&D (ATD)

Applied research to explore basic issues of battery performance and aging.

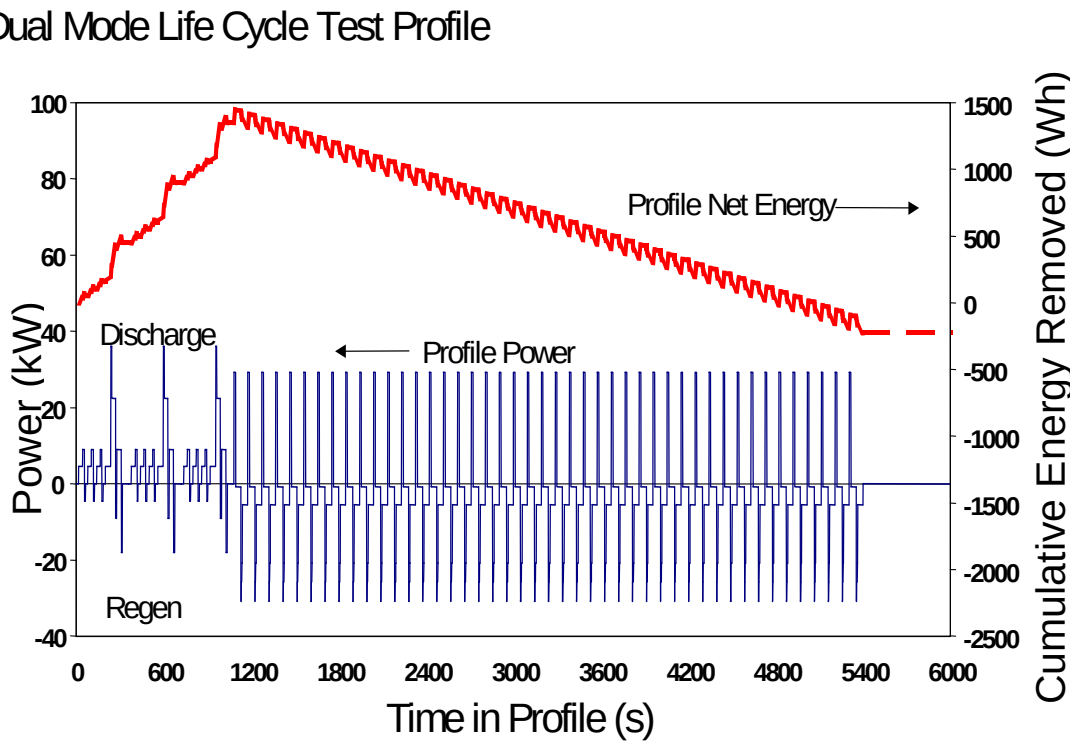
- Specialized tests and measurements
- Coin Cell Testing
- Molecular-scale modeling

INL performs High-Power Energy Storage R&D on batteries and ultracapacitors for various organizations

- FreedomCAR technical teams
  - **Electrochemical Energy Storage**
  - **Vehicle Systems Analysis**
- U.S. automakers
  - **Chrysler**
  - **Ford**
  - **General Motors**
- DOE Advanced Technology Development Program (Lithium-Ion)
- Heavy Hybrid Propulsion Systems Project
- Battery and ultracap manufacturers

High Power Energy Storage Test and Evaluation

- INL is a lead DOE lab for hybrid electric vehicle energy storage testing
- We develop national standards and procedures for performance and life testing of EV and HEV batteries and ultracapacitors
  - The test manuals developed by INL are the industry standard for testing EV and HEV batteries and ultracapacitors.
  - **Tests include:**
    - Static capacity
    - Thermal performance
    - Self-Discharge
    - Cold-cranking power
    - Efficiency
    - Pulse power
    - Calendar life
    - Cycle life

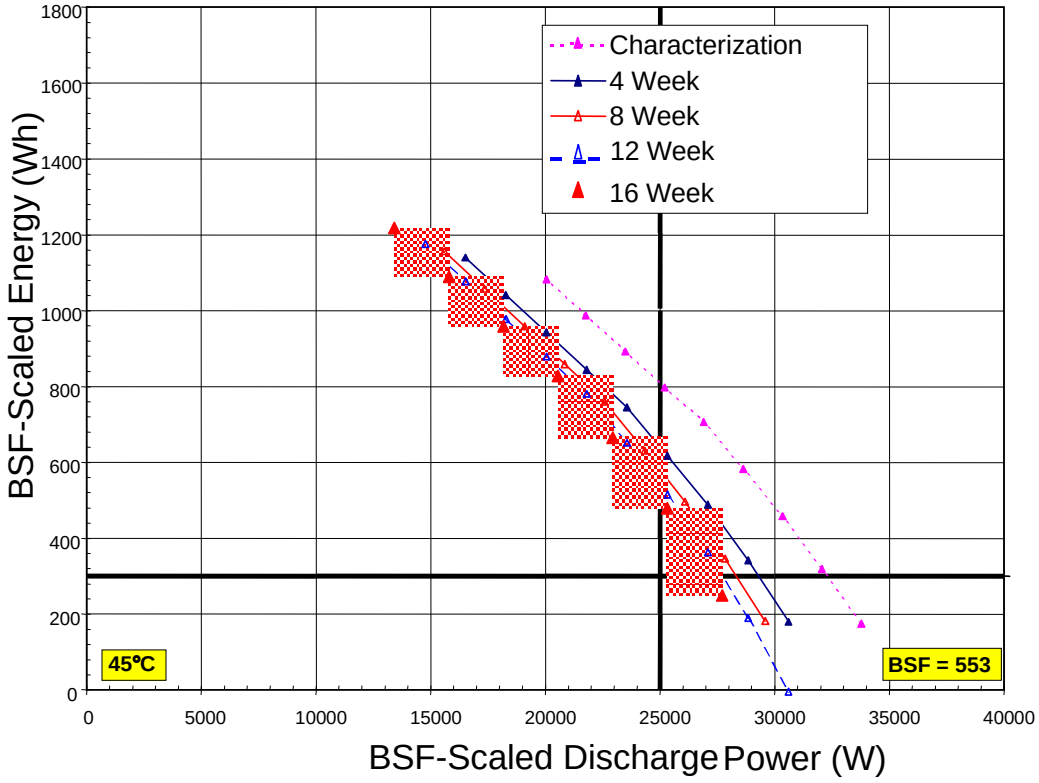


High Power Energy Storage Data Analysis

The department has pioneered the development of nationally-recognized standards and methodologies for test and analysis procedures for:

- conduct of operations,
- uncertainty analyses,
- battery scaling,
- thermal management,
- capacity/power fade, and
- battery life modeling.

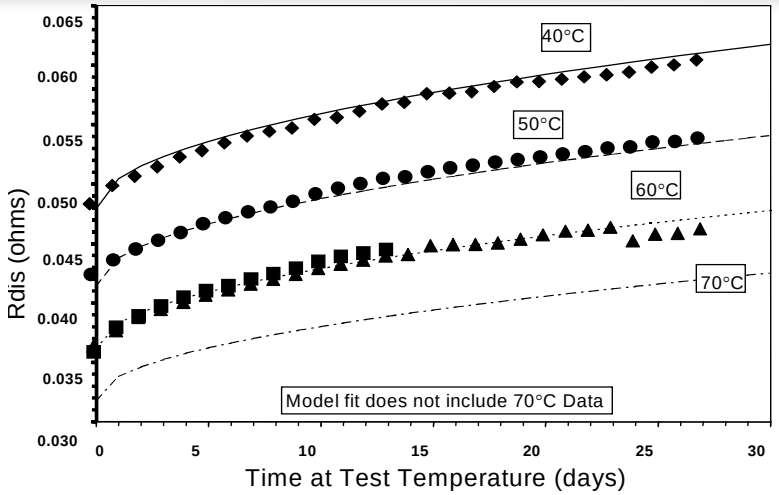
Scaled Available Energy at Several Times During Life Cycling



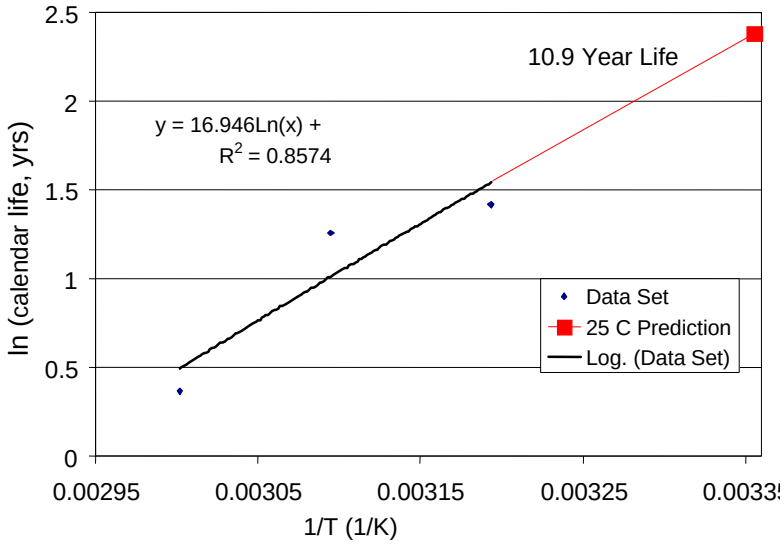
Electrochemical Performance Modeling

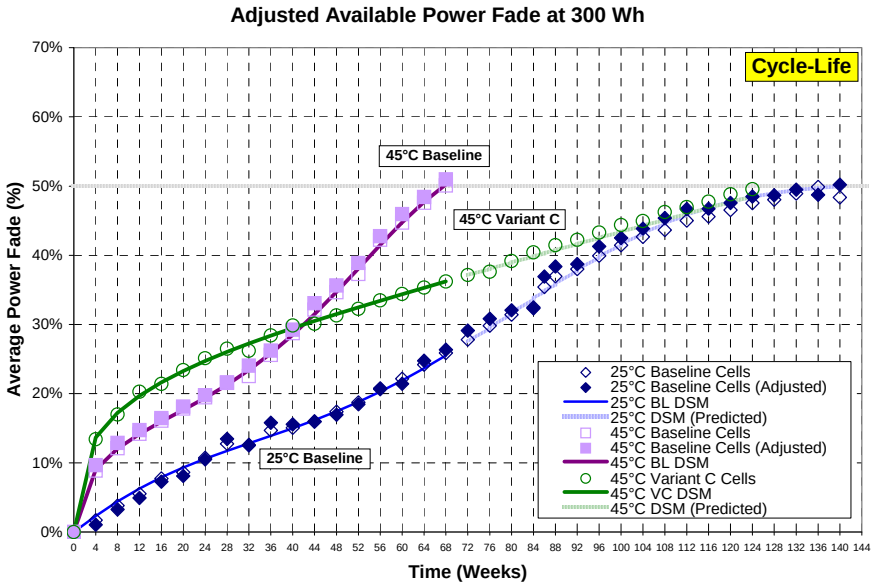
INL has developed novel calendar-life and cycle-life models, and supports Technology Life Verification Testing.

Calendar Life Discharge Resistance Data and Model Predictions for ATD Gen 1 Cells at 80% SOC



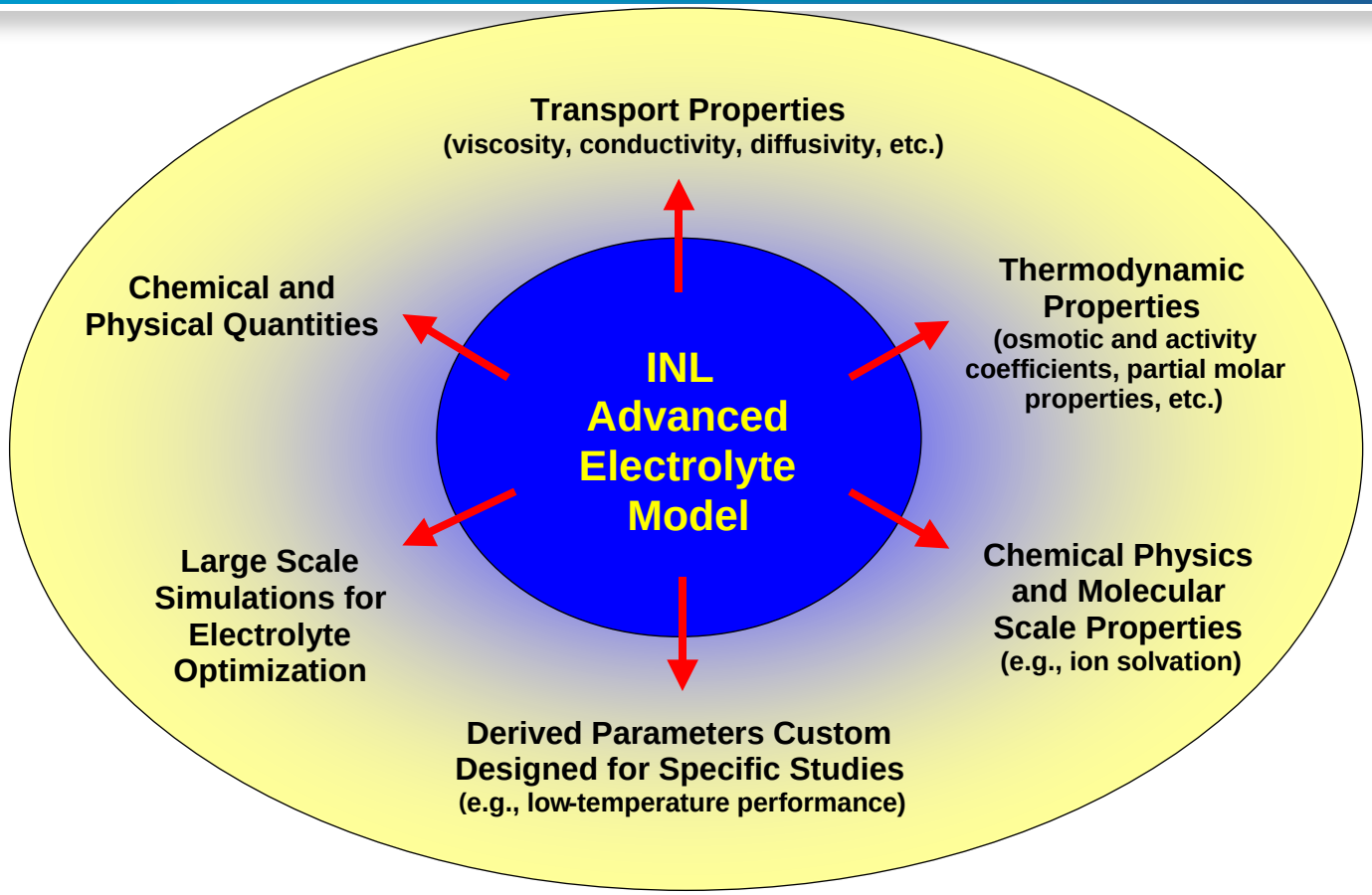
Calendar Life Model for Saft HP-12 Li-Ion Cells.





Average power fade vs. time for DOE-ATD Li-ion cells for test data (symbols) and predictions made by the DSM model (curves). The “adjusted” notation refers to data adjusted to true test temperature.

INL Advanced Electrolyte Model (AEM)



Key properties are generally predicted to within 5-10 % of experimental values over wide ranges of T and composition, with many predictions reaching agreement to within 5 percent or less.

In concert, these elements provide a sound basis for electrolyte characterization, screening and optimization for numerous applications.

Applied Research and Development
Small Coin Cell Construction Capability

- Work performed in INL Energy Storage Materials Laboratory (ESML).

- Ability to design the cell chemistry in small coin or “button” cells
  - Enables insights into the root-cause mechanisms for performance loss. Performance models can be developed once the mechanisms have been identified.
- Allows quick investigations of key chemistry issues
  - Electrode formation studies
  - Low-temperature performance studies
  - Electrode SEI optimization studies
- Models
  - Supports collaborative modeling work between DOE Lab participants participating in energy storage projects. Electrolyte transport properties provide a clear link between the INL Advanced Electrolyte Model (AEM) and the Electrochemical Cell Model (ANL).

Washington State Plug-In Hybrid Electric Vehicle Demo Regional Example

- The DOE Advanced Vehicle Testing Activity has established PHEV testing programs with Seattle-Tacoma area stakeholders (17 vehicles).
- Testing will be expanded to incorporate all of Washington State (total of ~27 vehicles)
- INL is currently exploring feasibility to integrate U.S. DOE and DOT test objectives
  - Reducing fossil fuel demand
  - Decreasing dependency on foreign oil
  - Decreasing congestion (and fuel use)
  - Improving air quality
  - Battery charging scenarios
- The demo will represent a substantial test platform for additional, more in-depth, PHEV infrastructure investigations, including working with key utilities

For a period of time, this demo will host the largest concentration of PHEVs in North America

Port of Seattle

King County
Always at your service

Puget Sound Clean Air Agency

TACOMA POWER
TACOMA PUBLIC UTILITIES

This work is supported by the U.S. Department Of Energy

Energy Efficiency and Renewable Energy

Vehicle Technologies Program

http://avt.inl.gov